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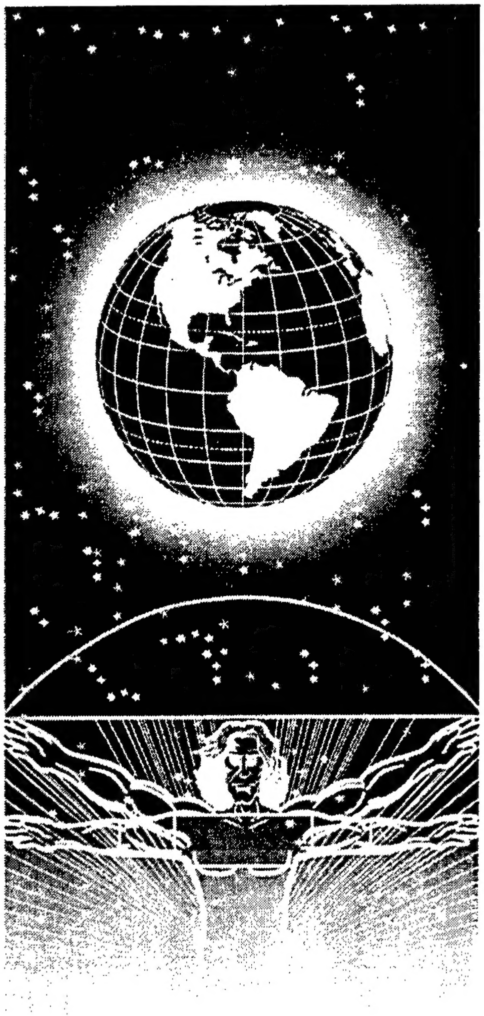

UNITED STATES AIR FORCE RESEARCH LABORATORY

THE EFFECT OF GLARE ON REGAN CONTRAST LETTER ACUITY SCORES USING DYE-BASED AND REFLECTIVE LASER EYE PROTECTION

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13. ABSTRACT *(Maximum 200 words)*

Current laser eye protection devices (LEPDs) are dye-based or reflective. While both technologies block the laser wavelengths, reflective LEPDs generally transmit more visible light than do dye-based LEPDs. Consequently reflective LEPDs are generally superior to dye-based LEPDs for the sparse light conditions of night. Reflective LEPDs are also better at maintaining a constant color appearance which is important for tasks requiring recognition of color coded information such as reading color maps or color cockpit displays. The advantages of reflective LEPDS, higher light transmission and better color recognition, need to be considered in association with other optical qualities of reflective LEPDs. One significant measure of optical quality is haze, which tends to be higher in reflective LEPDs. Wearing an LEPD with high haze can accentuate the impact of glare. Glare reduces visual acuity, particularly at low contrast levels. Differences in contrast acuity between dye-based and reflective LEPDs were investigated in the current experiment. Under indoor lighting (photopic), contrast acuity was separately measured with and without glare. In the absence of glare, contrast acuity remained high with all LEPDs. Only small decrements in the ability to identify very low contrast stimuli were found. In the presence of glare, the ability to identify low contrast stimuli was substantially reduced while wearing the reflective LEPDs with higher haze. While reflective LEPDs have been optimized for nighttime use, these data suggest that glare problems from the sun might be experienced while wearing reflective LEPD if protection is required during the day.

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INTRODUCTION

Laser eye protection devices (LEPDs) are being manufactured using various filter technologies. Early versions of LEPDs were dye based. These filters had good optics and generally low levels of haze, but they were rated poorly in simulators and flight tests under low light conditions because of reduced visual performance in terms of acuity and color recognition resulting from the substantial and unbalanced filtering of the already sparse light. More advanced dyes have improved both overall transmission and selective spectral filtering. For instance the FV-9 LEPD was preferred over the FV-6MR LEPD in low light conditions[1]. Newer reflective technologies (such as dielectric stacks) can further improve on the transmission and color shift problems. They can be engineered to have relatively narrower protection notches in spectral transmission and sharper transitions from high to low transmission compared to dye-based filters. However, these newer LEPDs are composed of many layers of thin films deposited on an optical substrate. Consequently, they have inherently higher levels of haze.

The physical measure of haze is defined by the National Bureau of Standards (NBS) as the ratio of the scattered light to the light transmitted through a filter. USAF standards require helmet visors to have haze of less than 2.0%. Given current manufacturing capabilities, it is easier to meet this standard with advanced dyes than with dielectric stacks.

The visual consequences of these differences in manufacturing technologies need to be evaluated. The Snellen eye chart provides a clinical measure of a person's ability to identify high contrast (96%), black-on-white letters under normal indoor conditions. The Regan contrast acuity test also uses letters, but provides measurements at five contrasts: 96% (like the Snellen), 50%, 25%, 11%, and 4%. Consequently it is more sensitive to changes in a person's ability to identify the low contrast stimuli that are common in naturalistic environments. The presence of glare (e.g, the sun in daylight or on-coming vehicle headlights at night) further reduces the ability to see fine detail[2].

The current research provides a comparison between a dye-based LEPD (moderate overall transmission and low haze) and two reflective LEPDs (higher overall transmission and higher haze) for Regan contrast acuity under both no glare and glare conditions. Both types of LEPD provide similar protection.

MATERIALS & METHODS

Three LEPDs in spectacle format were tested in this study. The dye-based absorptive LEPD (FV9) utilizes the currently most advanced dye that simultaneously maximizes protection outside of the visible spectrum (out-of-band protection), transmittance within the visible spectrum (in-band transmittance), and color constancy. The other two LEPD (WD1 and WD2) incorporate thin film reflective dielectric stacks. Compared to WD2, WD1 provides greater protection against lasers with long visible and near infrared wavelengths. As can be seen in the spectral transmission curves of Figure 1, WD1 and WD2 have higher overall transmission of the visible spectrum than does the FV9. WD1

and WD2 also have steeper cut-offs than the FV9. Previous work has shown that this promotes truer color constancy for WD1 and WD2 than for the FV9[3].

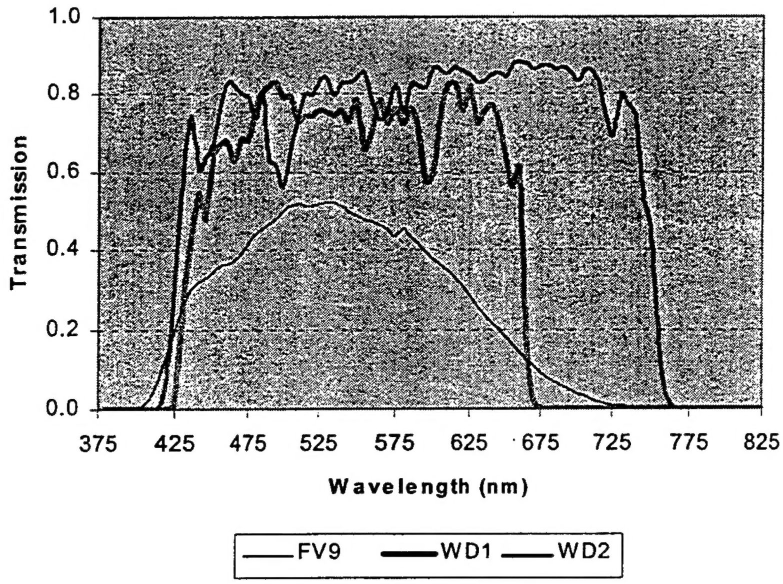

Figure 1. Spectral transmission of the three LEPDs.

The physical measurements of the three LEPD are presented in Table 1. Photopic luminous transmittance (PLT) was calculated (using CIE standard illuminant C) for the samples. Their haze was measured with a Hazegard Plus hazemeter in accordance with the standard established by the American Society for Testing and Materials (ASTM-1003)[4]. In addition, induced power and prism were measured on each LEPD, but were essentially identical and well below tolerance limits across our samples. They warrant no further discussion.

LEPD	*PLT*	*% Haze*	*Power (V,H)*	*Prism (V,H)*
Dye-based FV9	0.48	0.70	-0.04, -0.03	-0.16, 0.17
Dielectric Stack WD1	0.74	2.03	0.01, 0.00	-0.06, 0.04
Dielectric Stack WD2	0.83	1.34	0.04, 0.03	-0.13, 0.17

Table 1. Physical measurements on the three LEPDs.

Regan contrast acuities were measured using standard charts at five contrasts (96%, 50%, 25%, 11%, and 4%). The charts were presented in order from high to low contrast. After a screening for dominant eye, observers viewed the charts monocularly (dominant

eye; other eye patched) and were seated 10 feet from the charts under normal indoor florescent lighting (~900 lux). Additional florescent light fixtures were angled towards the charts so that the luminance of the chart was approximately 100 cd/m^2. Consequently vision was in the low end of the photopic range, but similar to clinical testing environments. The glare source (a small hemispheric ganzfeld) was a standard Brightness Acuity Tester (Mentor, model 22-4505). The highest setting was used, providing an illuminance of 100,000 lux. Observers adapted to the glare source for at least 5 minutes before starting the test. Contrast acuities were measured under four conditions: i) baseline, the naked eye, ii) looking through an LEPD, no glare source, iii) looking through the center of the glare source with no LEPD, and iv) through an LEPDand the glare source. Conditions ii and iv were repeated for each LEPD. Regan line number for each subject at each contrast in each condition was used to compute minimum visual angle (MVA). A small MVA indicates high visual acuity.

All of the data reported below are based on eight observers (five men and three women). It should be noted that six additional observers did not pass the criterion for inclusion (were not able to read at least four lines on the 4% chart in condition iii). It was necessary to establish the criterion for baseline performance with glare in order to be able to detect any impact of wearing an LEPD in the presence of glare. On the other hand, the visual performance of some users in operational situations with glare will be worse than the results obtained in this experiment.

RESULTS & DISCUSSION

The effect of the glare source on baseline Regan contrast acuity is shown in Figure 2. The two curves show contrast acuities measured (with the unencumbered eye) both with and

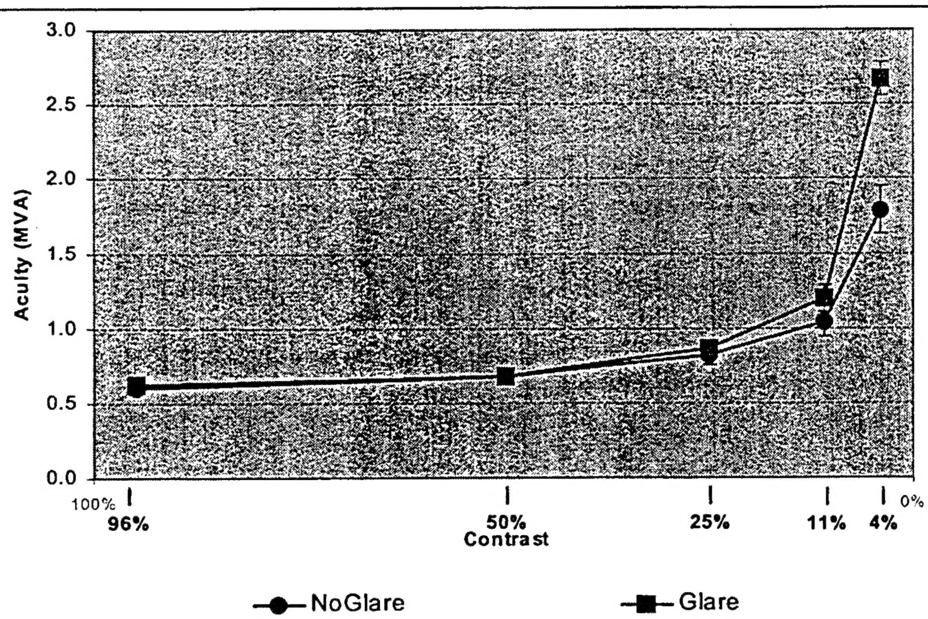

Figure 2. Baseline contrast acuity in the no glare and glare conditions.

without the glare source (i.e., conditions i and iii). The data shown are averaged across all eight observers. Note that the glare source degrades visual acuity (i.e., produces larger MVAs) only at the two lowest contrast levels, 11% and 4%.

To evaluate the impact of adding LEPDs, decrements in contrast acuity were computed by subtracting the MVA with LEPD from the baseline MVA. This decrement metric provides an indication of whether MVA is degraded (i.e., increases in MVA relative to baseline) due to wearing the LEPDs. Figure 3 presents the MVA decrements for the three LEPD for the no glare condition (conditions ii versus i). In the no glare condition, decrements were modest except at the 4% contrast. A 3x5 repeated measures ANOVA was conducted for the decrements in the no glare condition for the three LEPD at the five contrasts. The overall decrement was significant; $F_{(1,7)} = 11.97$, $p = 0.011$. The MVA decrement did not depend on LEPD ($F < 1$). A post hoc analysis revealed no difference between the three LEPDs even at the 4% contrast ($p > 0.20$). However, the magnitude of the MVA decrement depended on contrast; $F_{(4,28)} = 8.83$, $p < 0.001$. As can be seen in Figure 3, all three LEPDs reduced acuity at the 4% contrast in the no glare condition; $F_{(1,7)} = 25.08$, $p = 0.002$.

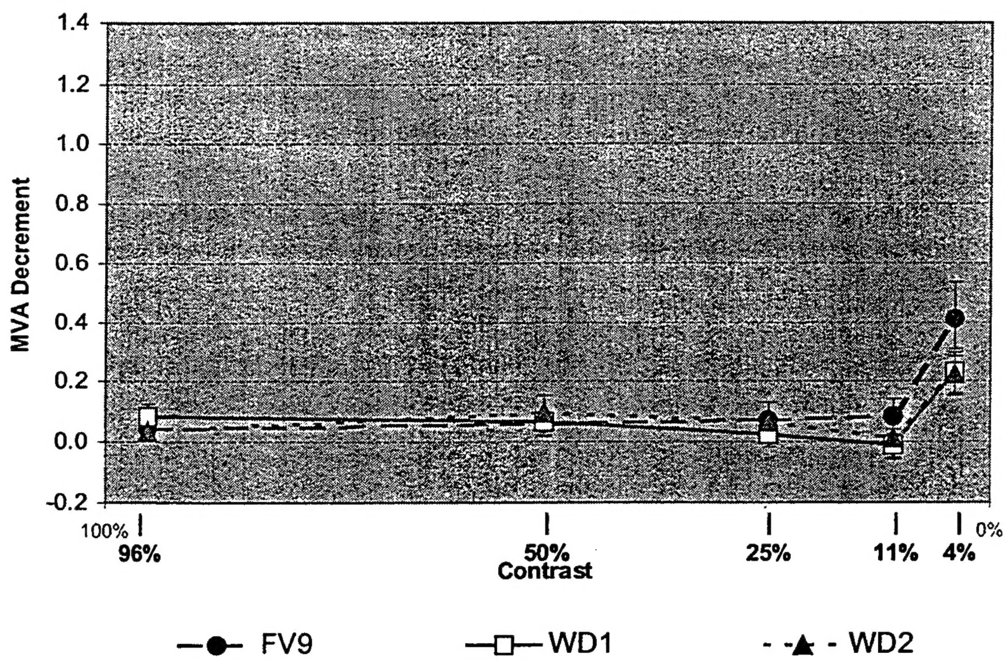

Figure 3. Acuity decrements for the three LEPDs in the no glare condition.

The MVA decrements due to wearing the LEPDs in the glare condition (conditions iv versus iii) are shown in Figure 4. Another 3x5 repeated measures ANOVA (three LEPD at the five contrasts) was conducted for these decrements in the glare condition. The overall decrement was significant; $F_{(1,7)} = 22.93$, $p = 0.002$. As can be seen in Figure 4, the MVA decrement depended on LEPD; $F_{(2,14)} = 21.22$, $p < 0.001$. Specifically, when

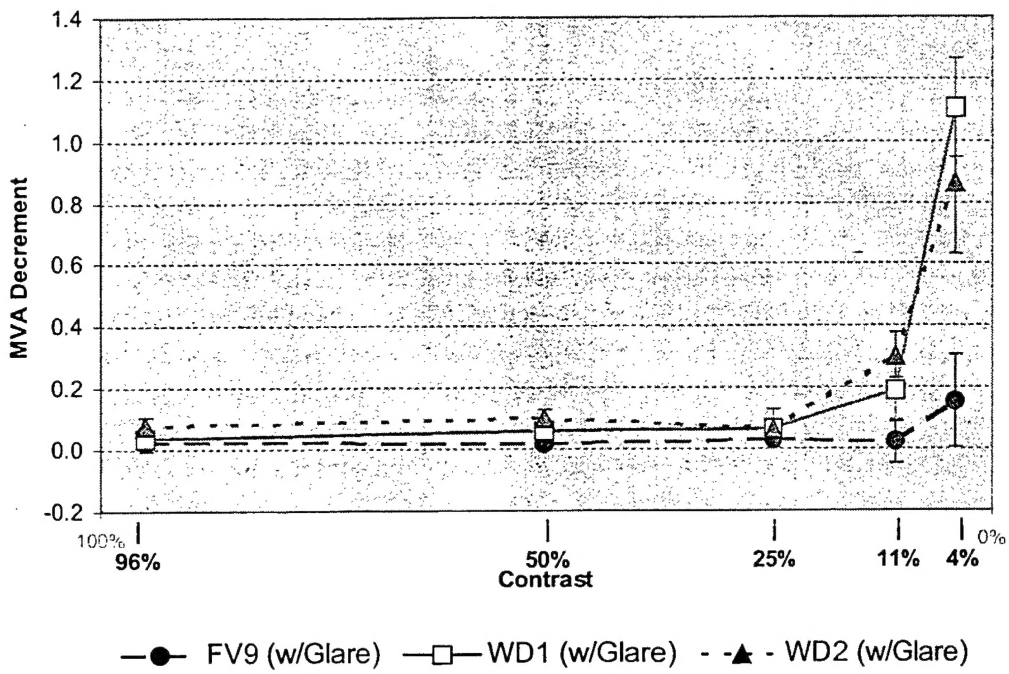

Figure 4. Acuity decrements for the three LEPDs in the glare condition.

glare was present, the FV9 LEPD produced less acuity degradation (i.e., smaller MVA decrement) than the reflective LEPDs (WD1 and WD2); $\underline{F}_{(1,7)} = 48.43$, $\underline{p} < 0.001$. In general, the magnitude of the MVA decrement was larger for the low contrast charts than for the high contrast charts; $\underline{F}_{(4,28)} = 18.53$, $\underline{p} < 0.001$. The significant interaction between LEPD and contrast ($\underline{F}_{(8,56)} = 8.69$, $\underline{p} < 0.001$) indicates that the decrement at low contrasts was larger for the reflective LEPDs (WD1 and WD2) than for the FV9. While post hoc analyses revealed no significant decrement for the FV9 in the glare condition ($\underline{F}_{(1,7)} = 1.65$, $\underline{p} > 0.23$), the overall decrement for the reflective LEPDs was significant ($\underline{F}_{(1,7)} = 33.93$, $\underline{p} = 0.001$) and the greatest degradation of acuity (i.e., greatest MVA decrement) for the reflective LEPDs was at lower contrasts ($\underline{F}_{(4,28)} = 31.07$, $\underline{p} < 0.001$). Under photopic lighting and with glare, the decrements for the reflective LEPDs were greater than for the FV9 at both the 11% contrast ($\underline{F}_{(1,7)} = 35.48$, $\underline{p} = 0.001$) and the 4% contrast ($\underline{F}_{(1,7)} = 41.48$, $\underline{p} < 0.001$).

CONCLUSIONS

In this experiment, the visual impact of haze on Regan contrast acuity was documented both with and without glare. The ability to resolve fine detail at five contrasts between 96% and 4% in a baseline condition (no LEP) was compared to performance for a dye-based LEP with low haze and for two reflective LEPs with higher haze.

No statistically significant differences were found between the dye (FV9) and reflective (WD1 and WD2) technologies in the absence of glare. When glare was not present, visual acuity remained high while wearing any of the LEPDs, except at the lowest contrast (4%) level. The decrements were modest even at the 4% contrast for the no glare conditions. In the presence of glare, low contrast acuity was degraded only minimally when wearing the FV9 LEPD. The lower transmission of the FV9 filter reduced the intensity of the chart stimuli, but also reduced the intensity of the glare source. On the other hand, the reflective LEPDs (WD1 and WD2) significantly reduced acuity in the presence of glare, especially at low contrasts (11% and 4%). It should be recalled that these measurements were made under normal indoor florescent lighting (100 cd/m^2). Whether similar effects would be found in low light conditions remains an unanswered question.

In designing an LEPD for nighttime applications, the goal is to provide protection from the laser while transmitting as much of the rest of the visible light as possible. Since reflective LEPDs (WD1 and WD2) transmit most of the visible spectrum at a higher level, they are better suited for most low light applications than the dye-based LEPDs (FV9). Also, their steep spectral cut-offs allow the WD1 and WD2 to maintain truer color appearance than the FV9. On the other hand, the ability to identify low contrast targets is better for the FV9 than for the reflective LEPD in the presence of glare at an indoor light level. While optimized for most nighttime applications, these results suggest that wearing reflective LEPD would make it difficult to identify low contrast targets at certain sun angles in daylight applications.

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